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Features

CHEMICAL EXPOSURES OF WOMEN WORKERS IN THE PLASTICS INDUSTRY WITH PARTICULAR REFERENCE TO BREAST CANCER AND REPRODUCTIVE HAZARDS*

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ABSTRACT

Despite concern about the harmful effects of substances contained in various plastic consumer products, little attention has focused on the more heavily exposed women working in the plastics industry. Through a review of the toxicology, industrial hygiene, and epidemiology literatures in conjunction with qualitative research, this article explores occupational exposures in producing plastics and health risks to workers, particularly women, who make up a large part of the workforce. The review demonstrates that workers are exposed to chemicals that have been identified as mammary carcinogens and endocrine disrupting chemicals, and that the work environment is heavily contaminated with dust and fumes. Consequently, plastics workers have a body burden that far exceeds that found in the general public. The nature

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of these exposures in the plastics industry places women at disproportionate risk, underlining the importance of gender. Measures for eliminating these exposures and the need for regulatory action are discussed.

Key Words: plastics workers, women's occupational health, breast cancer, endocrine disrupting chemicals

Women employed in the plastics industry are exposed to a multitude of toxic chemicals used in plastics production. These include styrene, acrylonitrile, vinyl chloride, phthalates, bisphenol-A (BPA), brominated flame retardants, heavy metals, a host of solvents, and complex chemical mixtures. Recently, public health concerns have emerged about the toxic qualities of substances contained in consumer plastics and their potential impact on children's and women's health.
Growing evidence of harm has led to public health initiatives in several jurisdictions to ban or restrict the use of these substances, in particular phthalates, BPA, and brominated flame retardants. Extensive biological monitoring campaigns have been launched to track the uptake of these chemicals in the general public. Despite this response to growing evidence of adverse health effects, little attention has been paid to the potential health impacts on more highly exposed plastics workers. Indeed, it comes as no surprise to see body burdens of these substances in workers that are significantly higher than those measured in unexposed workers and the general population [1- 6]. In this latter regard, it is important to note that levels currently detected in general populations can produce adverse effects in laboratory animals.

Our review indicates that women are at disproportionate risk due to the types of jobs they perform in the plastics industry and their particular biological vulnerabilities. Reflecting the general position of women in society, women perform the more labor-intensive jobs in the industry compared to men, who are more likely to work in the trades or to have supervisory roles. Of major concern is that occupational exposures to chemicals used in the plastics industry may contribute to the development of breast cancer and reproductive problems, because they either act as mammary carcinogens or disrupt the normal functioning of the body's endocrine system, or both. A recent study found that most plastics products release estrogenic chemicals [7]. Such endocrine-disrupting chemicals (EDCs) as phthalates, brominated flame retardants, and BPA are ubiquitous in the plastics work environment. Importantly, action at the endocrine level is such that significant adverse effects can be produced at concentrations thousands of times lower than the presumably safe levels established by traditional toxicology. For example, a dose of BPA that is 2,000 times lower (0.025 μg/kg/day) than the reference dose for human populations (50 μg/kg/day) can stimulate mammary gland development in animal offspring whose mothers were exposed to this low dose [8, 9]. To compound the issue, plastics workers are exposed to complex mixtures of a large variety of chemicals and combustion byproducts—described by a plastics worker as a "chemical soup"—whose combined effects may be greater than the sum of their individual effects on health.

This article is meant to sound an alarm about a major occupational health hazard that has not received adequate attention from the medical, scientific, and regulatory communities. To this end, we explore what is known about workplace conditions in the plastics industry, what is known about worker exposures to substances in the production process and their impact on women's health, and whether regulatory standards are protective. Finally, we offer some recommendations for changes that are needed.

WOMEN WORKING IN PLASTICS PLANTS

The link between chemicals used and/or produced in the plastics industry and the risk of breast cancer and reproductive harm is of particular concern because the plastics industry has a very high concentration of women workers. In Canada, for example, the plastics industry has a higher proportion of women workers than any other industry in the manufacturing sector, comprising 37 percent of the workforce [10]. In some areas like Windsor-Essex County in southern Ontario, where many plastics products are produced for the automobile industry, women constitute the majority of the area's plastics workforce [11].

Similarly, a high percentage of women work in plastics-related industries in the United States: almost 30 percent of workers manufacturing plastics products, one-third of the workforce producing rubber products, and one-quarter of the workers in the resin, and synthetic rubber, and fiber industry are women [12].

For the most part, the Canadian industry is dominated by small plants, 75 percent of which have 20 or fewer employees [10]. Many of these plants are not unionized, are economically marginal with low technological development, and have precarious employment as a result of the restructuring of manufacturing in the global economy.

THE PLASTICS PRODUCTION PROCESS

Plastics consist of polymers composed of long chains of repeating monomers. They are produced through multiple steps in different occupational settings, and workers are exposed to chemicals of concern at various stages of processing.

There are three basic stages of production and several different types of plastics manufacturing processes, as described in the *Concise Encyclopedia of Plastics* [13]. In the first stage, monomers such as vinyl chloride, styrene, BPA, acrylonitrile, butadiene, ethylene, and urethane are formed by processing crude oil and/or natural gas through a method the petrochemical industry calls *cracking.*

In the second stage, the resulting monomers are sent to resin producers to undergo the process of polymerization. Polymerization involves a chemical reaction in which the molecules of a monomer such as vinyl chloride are linked together to form large molecules with a molecular weight many times that of the original monomer. Resin producers convert monomers into polymer products such as polyvinyl chloride, polystyrene, nylon, acrylonitrile-butadiene-styrene (ABS), and polyurethane. Resins are then shipped to plastics products manufacturers in the form of powders, liquids, or pellets. In the third and final stage, polymers are processed by downstream industries to make paints, adhesives, and plastics products such as pipes, packaging, automotive parts, toys, fabrics, siding, medical equipment, and tools.

Polymers are divided into two main classes: thermoplastic and thermoset. Thermoplastic polymers can be repeatedly softened and reshaped with the application of heat and pressure. Common examples include polyvinyl chloride (PVC), polyethylene, polystyrene, and acrylics. In contrast, thermoset materials such as epoxy undergo a chemical reaction that results in a permanent product that cannot be softened or reshaped. Well-known thermosets include polyurethane, phenolics, ureas, and epoxies. Using one of these two classes of processing, resins are formed into different plastic products.

Among the several methods used to fashion plastics products, injection molding, reaction molding, and foam molding best illustrate the major techniques used to process thermoplastics and thermosets.

Injection molding is the most widely used technology to process thermoplastics. In this process, polymer resins in the form of pellets are injected into a screw feed chamber where they are melted and carried under high pressure into a mold of desired shape. Once cooled, the parts are ejected and retrieved by workers who typically trim, drill, grind, sand, paint, and decorate the part into a finished plastic product.

Reaction molding is similar to injection molding except that the thermosetting polymers that are used require a catalyst and a curing reaction within the mold. Polyurethane is a widely used thermosetting polymer.

Similarly, thermoset foam molding involves injecting a chemical mixture into a mold where it reacts and expands to fill the mold with thermosetting cellular plastic. During processing many other materials are added to alter the resin's properties. These additives can include heavy metal stabilizers, phthalate plasticizers, antioxidants, blowing agents, lead or cadmium pigments, brominated flame retardants, curing agents, and lubricants.

EXTENT AND NATURE OF WORKERS' EXPOSURES

Workers' Reports on Working Conditions/Exposures

The extent of workers' exposures is determined by their job tasks and the quality and existence of exposure controls in the plants where they work. During every step in the plastic production process, contaminants are released as a result of the handling and mixing of resins and additives, and their processing under high heat and pressure. Gases and vapours containing residual monomers, as well as additives such as phthalates, heavy metals, flame retardants and various hydrocarbons, are released during venting and normal processing. Additional dust and vapours are produced during finishing operations containing various monomers, additives, solvent and paint fumes. At the same time, the overheating of plastics during machine malfunctions and purging operations results in thermal decomposition and the release of chemical byproducts. In contrast to monomer and resin production, which typically employ closed-looped containment systems that keep material handling to a minimum, molding and fabricating are relatively open operations permitting the release of contaminants into the work environment. These production jobs are typically labor-intensive and are more likely to employ women.

Detailed descriptions of workers' exposures in plastic production are limited. Published research seldom contains data describing typical, day-to-day conditions as experienced by workers themselves [14]. A case-control study of occupational exposures and breast cancer being conducted by Brophy et al. in Southwestern Ontario, Canada, required qualitative data to inform its exposure assessment and coding process for several occupational environments, specifically agriculture, health care, and automotive manufacturing, which includes plastic parts production [15]. A qualitative study was undertaken concurrently to gather the required information. The study and its methods were approved by the research ethics board (REB) at the University of Windsor, the host institution. Experiential data were gathered between 2008 and 2010 through individual and group interviews [11, 16]. Utilizing the same approved methods, supplementary group interviews were conducted in 2011 in collaboration with the National Network on Environments and Women's Health. Local unions representing plastics workers and the Canadian Auto Workers union national office assisted in the recruitment of a total of 40 individuals from 13 local plastics plants in Windsor, Ontario, for the study and supplementary interviews. Facilitated discussion included open-ended questions about the participants' working conditions, job tasks, plant layout, chemicals used, protective controls, changes that occurred over time, exposure concerns, improvements needed, and perceived barriers to gaining improvements. One of the data-gathering techniques used was *hazard mapping*. This approach has been validated in other occupational health studies [17, 18]. Such visual representations enhance participants' recall and can result in rich, detailed descriptions of the current and past work environment. The interviews were audiotaped and transcribed.

The first-person accounts, which are reported without participant identifiers, revealed personal experiences regarding usual practices and related exposures, as well as malfunctions. For example, one of the study participants described her experience during a routine molding machine malfunction: "I looked behind the mold and I could see a big cloud of smoke and then there was a fire and . . . the smoke is clearing and here is one of our workers standing in the middle of it. You couldn't even see her and it was just plastic burning" [16].

The study included a review of a small collection of government and company hygiene consultant reports provided by members of the plastics workers' union health and safety committee [19, 20]. These reports were related to various inspections carried out in several of the workplaces represented by study participants. The inspectors and consultants reported conditions similar to those described by study participants. For example, a common concern expressed by study participants was the lack of ventilation. A participant commented that "We do plastic injection molding. We smell a lot of smells, a lot of fumes, stuff like that—so I'd like to see actually more local exhaust" [16]. Hygienists and government inspectors reported that the machines they inspected were releasing chemicals into the air and that local exhaust ventilation is rare. A 1995 Ontario Ministry of Labour report investigating worker complaints from ABS injection molding machines documented releases of acrylonitrile, benzene, styrene, acetaldehyde, xylene, and toluene [19]. A hygiene consultant visiting an Ontario plastics plant in 2004 reported: "different odors were perceived in different units of the plant and mold injection units were not equipped with local exhaust ventilation" [20]. One woman working in a plant with poor exhaust ventilation described the following effects: "I don't know if it's from the smoke or if it's from the fumes. You smell fumes, you taste [it] in your mouth, and then you get—it's like a light-headedness, dizziness" [16].

Before packaging and shipping, molded plastics are trimmed, drilled, and sanded; some also need to be assembled, painted, and decorated. Workers performing these tasks can be exposed to polymer dust from sanding and grinding operations as well as to paint and solvent vapours. Workers noted: "while on assembly near decorating, the parts were frequently spray-painted with gray paint. Since we were close by, we would also get a dose of spray-paint all over us. It was everywhere. We would look like the 'Tin Man' in the Wizard of Oz" [16].

Workers handle various plastic fabrics impregnated with flame retardants and phthalates used in car interiors during the finishing process. Exposures can be intense, as one worker observed: "When stitching fabric we would be encased in dust. When you blew your nose the mucus was loaded with this dust. It was treated with antimony trioxide and [tris (2-chloroethyl) phosphate, a flame retardant commonly known as "tris"]. We have skin and breathing problems. The material was still wet with this stuff when we worked on it" [16]. A government inspection report regarding the process described by the worker noted: "There is no exhaust ventilation on 3 of 4 sewing machines and it appears dusty" [19]. The inspector suggested improvements, but did not issue orders.

The overheating of plastic materials is another source of polymer fumes, smoke, and gases not only during processing, but especially during cleaning, purging, and maintenance operations. When molding machines are cleaned and purged, resins and purging agents are forced through plastic presses at very high temperatures.

Workers interviewed about their experiences said that when the machines were purged, "hot stinky gunk would sit there and off-gas" [16].

Although inspection reports and workers' observations indicate that dust and fumes were constant problems and ventilation was inadequate, often hygiene sampling did not find levels above the occupational exposure limits (OELs). As one woman commented: "The Ministry comes in and does testing and it's never over the exposure limit. We would run ABS and there were people suffering from symptoms and the test results always came back under what was allowed" [16].

On rare occasions, air sampling showed that contaminants did exceed acceptable levels. A government inspection of a Windsor plastics plant in 1990 found volatile organic compounds to be above the short-term OELs. The inspector noted: "Exhaust fan in the gluing booth, exhausts . . . inside the plant and air is re-circulated. With increase in production, large amounts of solvent vapors are produced" [19]. The inspector recommended that the booth exhaust air be directed outside, but no orders were written to the company despite the clear violation of the Regulations under the Ontario Occupational Health and Safety Act, which prohibit exhausting contaminated air into the work environment—a regulation that had been in place for over 20 years.

Toxic Body Burden

Although the authors do not advocate biological monitoring or the use of biological exposure limits as a means to protect worker health, we reviewed literature that compared the body burdens of EDCs found in studies of workers with those found in studies of the general population. Since the experimental work of endocrinologists shows adverse effects at levels found in the general population, these comparisons were used to assist in assessing occupational risk.

Our review of the biomonitoring studies found that workers involved in plastics processing have chemical body burdens significantly higher than those found in "non-exposed" referent groups or the general population. The chemicals measured included acrylonitrile, styrene, phthalates, and BPA. A Dutch biomonitoring study of plastics workers found that exposed workers had average acrylonitrile (AN) concentrations in urine that were 11 times higher (AN/U 22.1 μg/g) than the average concentration found in non-smoking/non-exposed workers (AN/U 2.0 μg/g), even though air concentrations for exposed workers at the workplace (AN/A 0.13 ppm) were below the established limit (AN/A 2.0 ppm) (AN/A 4.0 ppm)/MAC-TWA in the Netherlands and 2 ppm established by the U.S. Occupational and Health Administration at the time of the study. (These were calculations from the study's data for arithmetic means for non-smoking controls and non-smoking exposed workers.)These concentrations persisted on days off, indicating that AN was bio-accumulating [1]. Similarly, styrene has been found at elevated levels in plastics workers. An Italian study comparing blood-styrene levels found concentrations in exposed workers (1211 μg/L) levels 5.5 times higher than levels found in what the authors describe as a “normal” population (221 μg/L) [2]. Another Italian monitoring study found that job tasks were the most important predictor of styrene exposure, with levels of styrene in urine directly proportional to the level of manual handling of materials [3].

Phthalates studies provide another example of workers with high chemical body burdens. A study conducted by Liss and colleagues found significant uptake in workers exposed to di-(2-ethylhexyl) phthalate (DEHP) [4]. Researchers found high urinary phthalate concentrations even though air sampling failed to detect them. In metabolite studies that were combined with air sampling, urinary phthalate levels were significantly above levels found in general populations, even though air sampling showed levels far below exposure standards and in trace amounts [5].

Although few occupational studies have been published, BPA was measured in the urine of Japanese workers who applied epoxy resins containing bisphenol-A diglycidyl ether (BADGE) and found to be significantly higher in 42 exposed workers (1.06 μmol/mol) compared to 42 unexposed (0.52 μmol/mol) controls [6]. The authors noted that the levels found in controls were similar to levels found in the general population.

HEALTH IMPACT OF HAZARDOUS CHEMICALS USED IN PLASTICS PRODUCTION

It is generally accepted that the plastics processing work environment is potentially contaminated by residual monomers, polymers, and various additives, including plasticizers, stabilizers, pigments/colorants, flame retardants, activators, lubricants, and fillers, as well as solvents, paints, and finishing agents used in the decorating process. Some of these substances are mutagenic and known to cause cancer in humans, some are suspected of causing cancer, and some have been identified as endocrine-disrupting chemicals that may promote cancer.

Plastics workers have expressed concerns about their cancer risk. One woman from a Windsor plastics plant observed, “We’ve had quite a few women, one woman, actually right now is going through her treatment for breast cancer, started last week . . . and we’ve had four within the last ten years I would say. So yeah, it’s always in the background of your mind when they’re purging the machines. . . . We’ll yell over at another co-worker and say I wonder what this smell is, if it can affect us” [16].

Monomers of Concern

Although monomers are generally used up during polymerization, residual monomers such as vinyl chloride, styrene, acrylonitrile, BPA, formaldehyde, butadiene, ethylene, and urethane can still be released during the production of resins or thermal processing [21]. A recent rating of the toxicity of various plastics substances, conducted by Swedish scientists, demonstrates the high degree of toxicity of many monomers [22]. Their study ranked 55 polymers used in plastics production according to degree of toxicity and seriousness of health effects based on monomer hazard classifications. Polymers of highest concern contained monomers classified as mutagens and/or known or probable carcinogens. Thirty-one of 55 polymers contained monomers belonging to the two highest hazard levels on a scale of five—in particular, polyvinyl chloride, styrene-acrylonitrile and acrylonitrile-butadiene-styrene.

Monomers, such as vinyl chloride and formaldehyde, are known to cause cancer, and are classified by the International Agency for Research on Cancer (IARC) as human carcinogens [23]. Vinyl chloride was first identified as the agent responsible for angiosarcoma in workers making polyvinyl chloride [24], while more recent studies show an association between vinyl chloride and testicular cancer [25] and possible association with male breast cancer [26]. Formaldehyde has also been linked to an increased risk of female breast cancer in a 1995 U.S. study of industrial workers [27].

Many monomers are found to be mammary carcinogens. In their comprehensive database of substances shown to cause mammary gland tumors in animals, scientists at the Silent Spring Institute in Massachusetts have listed three monomers used in plastics production: vinyl chloride, acrylonitrile, and styrene [28]. Styrene is the second-most-used monomer. Acrylonitrile has been linked to genital abnormalities in children born to exposed mothers and may have endocrine-disrupting effects [29]. Styrene, in addition to being a possible carcinogen, is identified as an endocrine disruptor [30].

Other monomers are either known or suspected of being EDCs with the potential to put workers at risk for breast cancer. The monomer 1,3-butadiene has been shown to induce mammary gland tumours in rats and has been classified by IARC as a Group 2A carcinogen [31]. The most well-known endocrine disruptor among widely used monomers is BPA. A large-scale literature review sponsored by the U.S. National Institutes of Health concluded that BPA concentrations in human populations were comparable to levels of BPA that produced "organizational changes in the prostrate, breast, testis, mammary gland, body size, brain structure, chemistry and behavior of lab animals" [32]. Studies demonstrate that significant effects can be produced by very small doses. For example, studies on BPA found adverse effects at doses far below referent levels for human populations. Some effects included mammary gland stimulation in offspring at maternal dose of 0.025 μg/kg/day, alterations in immune function at doses of 2.5–30 μg/kg/d, early onset of sexual maturation after maternal dose between 2.4 and 500 μg/kg/d, and decreased sperm production and fertility in males at maternal doses between 0.2 and 20 μg/kg/d [33-35, 8, 9]. These studies suggest that BPA may increase the risk of breast cancer and reproductive abnormalities in women. In this latter regard, human BPA studies have identified adverse effects in women with a high body burden that include recurrent miscarriages, ovarian cysts, obesity, and endometriosis [36-39].

Additives with Toxic Properties

Plastics workers are also exposed to numerous chemicals added to resins. Many of these additives have potentially toxic effects, and some are identified as either carcinogens or endocrine-disrupting chemicals or both. Of these additives, phthalates raise many concerns for workers in the plastics industry. The phthalate DEHP, used to plasticize PVC, may be estrogenic. It has been implicated in the development of male breast cancer and testicular cancer and may cause reproductive problems among both men and women who work in PVC fabricating operations [25, 26, 40]. A study of a phthalate-exposed population in northern Mexico found an elevated breast cancer risk among women [41]. A recent study of male PVC workers in Taiwan found an adverse effect on the semen quality among men with the highest concentrations of DEHP [42].

Heavy metal additives such as lead, cadmium, organic tin, barium, calcium, and antimony compounds used as pigments and stabilizers are highly toxic. Lead compounds are classified by IARC as possible carcinogens and cadmium is a known human carcinogen [23]. Lead is an endocrine disruptor with reproductive effects in both men and women [43].

Flame retardants such as polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDE) are strongly estrogenic and some are classified by IARC as possible carcinogens [23]. Tris is identified as potentially "toxic to reproduction" [44]. Antimony trioxide has been shown to cause respiratory cancer in female rats and negative reproductive effects in humans [45] and is classified by IARC as a possible carcinogen [23].

Other Chemicals of Concern

In addition to the many carcinogenic and/or endocrine-disrupting chemicals used in thermal processing, there are several other cancer-causing and hormone-disrupting substances common to most manufacturing jobs. For example, polycyclic aromatic hydrocarbons (PAHs), emitted by machining, fuel combustion, and other decomposition processes, have been identified as mammary carcinogens in animal testing [28]. Benzo(a)pyrene, one of the PAHs produced when combustion is incomplete, has been classified by IARC as a human carcinogen [23]. The widely used solvents benzene, methyl ethyl ketone (MEK), and toluene have been found to cause mammary tumors in animals [28]. Researchers suggest that organic solvents may initiate or promote breast cancer, and many are considered to be endocrine disruptors [46].

Endocrine-Disrupting Chemicals and Windows of Vulnerability

Current exposure limits do not take into account possible effects at very low concentrations characteristic of endocrine disruptors, which typically range in the parts per trillion [47]. Flying in the face of the traditional toxicologic paradigm, EDCs may not exhibit a linear dose-response relationship. Indeed, endocrine researchers generally accept that in some circumstances low doses may have a greater effect than higher doses. The endocrine system is a sensitive system that regulates growth, metabolism, sexual development, and reproduction. It can be disturbed by very low doses of substances that can mimic or trigger estrogen—a very powerful tumor promoter linked to the development of breast cancer. Underlying the disproportionate risks to women workers is the fact that for substances that act through the endocrine system, sex and gender are critical. The timing of the exposure in relation to biological developmental stages is particularly significant [48]. There are critical windows of vulnerability where women may be more susceptible to the effects of endocrine disruptors, particularly those periods leading up to the end of a first full-term pregnancy, when breast tissue becomes fully differentiated [46].

Health Effects of Complex Mixtures

Plastics workers are rarely exposed to one substance at a time. Instead, they are exposed to complex mixtures of chemicals used and produced during the production process, and they often rotate through the plant where different jobs are running simultaneously. As one woman said: "We are pretty much being exposed to different materials every day . . . like one machine was ABS, another machine was nylon and they were ten feet away from each other" [16]. A government inspector's report identified air concentrations of hydrocarbons and halogenated hydrocarbons including methyl ethyl ketone, acetone, alcohol, and xylene in one workplace, adding that "fumes were strong and several workers developed symptoms of nausea, dizziness and headache" [19]. Another woman asked: "What's the synergistic effect of everything being mixed together?" [16].

Understanding the health effects of exposures on workers is not straightforward. For example, assessing the effects of vinyl chloride monomer is complicated by the fact that polyvinyl chloride resin includes not only vinyl chloride monomer but additives such as phthalate plasticizers, heavy-metal–based stabilizers, pigments, and processing aids, all chemicals with possible adverse health effects.

Several studies add weight to the hypothesis that exposure to complex mixtures of EDCs may have additive and/or synergistic effects. In a study conducted of women with breast cancer, researchers found an increased risk for leaner women exposed to a combination of endocrine-disrupting pesticides [49]. Adding to the significance of this finding is the fact that leaner post-menopausal women normally have a lower risk of breast cancer. A recent Spanish study found that women exposed to multiple environmental estrogens were at higher risk of giving birth to male babies with abnormal genital formations [50].

EPIDEMIOLOGIC EVIDENCE RELATED TO PLASTICS MANUFACTURING

Women who participated in the study spoke openly about their health concerns. "We had lots of cancers in our plant . . . 15 women and two men—all under 50 years old. And we also had one guy with breast cancer, which seemed odd. I never knew men could get breast cancer" [16]. Another woman told us: "I worked at the plastic plant for five years and then developed breast cancer when I was 32. There are six or seven breast cancers that we know of. They are all younger than 50" [16]. Several women spoke of miscarriages, infertility, and negative reproductive outcomes among their co-workers. The epidemiologic evidence suggests that such concerns and anecdotal accounts about breast cancer and reproductive abnormalities in plastics production are justified.

Breast Cancer

The case-control study by Brophy et al. that utilized descriptive data from the qualitative study [11, 16] found a more-than-doubling of breast cancer risk among women who had worked in automotive plastics manufacturing for 10 years and were assessed as having been highly exposed to EDCs and/or carcinogens (OR = 2.68; 95% CI 1.47-4.88). The risk for women who worked in food canning, where it is plausible that they were exposed to BPA from can linings, also more than doubled (OR = 2.35; 95% CI 1.00-5.53). Their risk for premenpausal breast cancer rose to more than five-fold (OR = 5.70; 95% CI 1.03-31.5) [15]. A 1998 study by Petralia et al. identified excess risk of breast cancer among women exposed to organic solvents and benzene (SIR = 1.8; 95% CI 1.4-2.3) in the plastics and rubber industries, which share many common exposures [51].

A 2008 study by Ji et al. of women working as plastics processing machine operators reported a doubling of breast cancer risk (OR = 2.0; 95% CI 0.9-4.3) [52]. The connection between breast cancer and employment in the plastics industry is strengthened by the finding of an excess risk of male breast cancer among workers in the rubber and plastics industries [26]. Male breast cancer is a rare event constituting only 1 percent of all diagnosed cases of breast cancer.

In 2010 Labreche et al. linked an excess risk of breast cancer with occupational exposures to synthetic textile fibres, acrylic fibres, and nylon fibres when exposure occurred before age 36 (OR = 7.69; 95% CI% CI 1.5-4.0) [53]. This supports the contention that women are vulnerable when breast tissue has not been fully differentiated. It is important to note that modern textiles consist mostly of polymer resins and additives, which are used extensively in plastics manufacturing. Similarly, a 2008 case-control study by Shaham et al. identified increased risk of breast cancer among women working in textiles and clothing industry (OR = 1.8; 95% CI 1.1-3.0) [54].

A 2011 study by Villeneuve et al. found an elevated risk of breast cancer for women employed in rubber and plastics products manufacturing (OR = 1.8; 95%

CI 0.9-3.5) [55]. The authors cite occupational exposure including night-shift work, solvents and EDCs as possible risk factors requiring further assessment.

Reproductive Health

In addition to the scientific literature that suggests a link between breast cancer and work in the plastics industry, there is considerable evidence that exposure to plastic substances affects reproduction. Workers also expressed concern about reproductive problems experienced in the workplace. One study participant observed that: "many men and women had reproductive problems like sterility . . . as well as lots of miscarriages, and some kids were born with developmental problems" [16].

A 1993 review by Baranski of the scientific literature on the adverse effects of occupational factors on reproduction cited many studies showing an increased risk of spontaneous abortions for women working in the plastics and rubber industries, and in women exposed to organic solvents [56]. The review found many studies showing infertility among women working in plastics and related industries, including synthetic rubber, caprolactam (a monomer used in the production of nylon), and styrene production. Other well-documented reproductive problems included delayed conception, premature delivery, and congenital malformations in the offspring of women rubber workers.

In 2009 an increased risk of infertility among women working in the plastics industry (RR = 1.23; 95% CI 1.01-1.48) was identified in a case-control study by Hougaard et al. [57].

CONTROLLING EXPOSURES AND FINDING ALTERNATIVES

Based on the available information regarding the toxicity of substances used in the plastics industry and our knowledge of workers' exposures, it is clear that more effective measures must be put in place.

Clearly, our current system of numerical limits does not protect plastics workers' health. As the interviews and review of government inspections reveal, women working in the plastics industry experienced serious symptoms and illnesses even though periodic air sampling results were often below the OELs. An early critique of OELs pointed out that only a minority of studies showed no adverse health effects below the established limits [58] and that the OELs were heavily influenced by industry to keep costs and liabilities down [59]. A more recent critique found clear scientific deficiencies in the determination of limits [60]. An international quantitative study noted the tendency for exposure limits to decrease over time, but expressed concern over the wide variation among limits for the same chemical in different countries [61]. Another limitation of OELs is their dependence on air sampling, which evaluates only how much of a chemical enters the body through inhalation, even though many chemicals are also absorbed through the skin, or inadvertently ingested. In addition, air samples may not be representative of usual conditions. Moreover, the OELs do not address possible health effects of exposure either to complex mixtures or to EDCs at low doses. The reliance on OELs needs to be completely re-evaluated in light of the growing understanding of the effects of EDCs on health. This may be particularly relevant to women workers whose health has been largely ignored in occupational health studies [62, 63] and in light of the growing evidence of reproductive and cancer risks from low-dose exposure to EDCs. Indeed, the most prudent protective measure would be to eliminate altogether occupational exposures to EDCs. In other words, we need a regulatory system that requires the elimination of worker exposures through substitution and engineering controls, particularly as they relate to EDCs, rather than one that relies on ineffective air monitoring and adherence to arbitrary exposure limits [64].

Unfortunately, free trade agreements and globalization have eroded worker protections. Companies, particularly those in such labor-intensive industries as plastics manufacturing, typically claim that protective safety measures are too costly and will lead to plant closures. International industry-wide standards would eliminate the companies' advantage of shutting down and moving to more poorly regulated jurisdictions.

Put simply, hazards must be controlled at the point of production. This can be achieved by substituting hazardous substances, enclosing hazardous processes, or re-engineering processes to eliminate the hazardous steps during production.

Several researchers make a convincing case for replacing EDCs in plastics production. Yang and colleagues, who found that most plastics products are hormonally active, argue that it is possible to substitute relatively inexpensive non-estrogenic monomers and additives [7]. A study of phthalates and their alternatives conducted by the Lowell Center for Sustainable Production also identified a large number of substances that could replace the use of phthalates as plasticizers, as well as plastics substitutes that use fewer and less harmful additives than those required for PVC products [65]. Importantly, the effectiveness of this approach would depend on a requirement to test substitute chemicals for endocrine-disrupting activity to ensure the safety of both plastic products and occupational environments. Where substitution is not achievable, employers should be required to introduce stringent process controls to prevent worker exposure.

CONCLUSION

This review raises major issues about health risks to women working in the plastics industry that have important implications for regulatory reform.

First, we found through worker interviews and a review of hygiene reports that plastics workers labor under very poor working conditions marked by inadequate to non-existent exposure controls and lax enforcement. What came through clearly is that enforcement is an unmitigated failure. By declining to issue orders to comply with occupational health regulations, inspectors, in effect, issue permits to endanger workers. Regrettably, there is good reason to believe that the examples provided represent the rule, rather than the exception [66]. The prevention of occupational disease requires a commitment to the principle of enforcement. To be effective, mechanisms must be put in place so that the cost of noncompliance is greater than the cost of compliance. In order to work, the system must be adequately resourced so that the likelihood of catching violators is high. Importantly, inspectors and hygienists must be empowered to focus on workers' health complaints and symptoms, their working conditions, and the state of exposure controls when issuing orders—and not primarily on exposure numbers and compliance with OELs, for the reasons cited above.

Second, through a review of the known health effects of substances used in the plastics industry we were able to ascertain that workers are chronically exposed to substances that are potential carcinogens and endocrine disruptors. This situation is aggravated by the fact that workers are exposed to complex mixtures of hazardous substances that may have additive and/or synergistic effects.

Third, we found through our review of the literature that workers carry a body burden of plastics-related contaminants that far exceeds those documented in the general public.

Fourth, existing epidemiologic and biological evidence indicates that women in the plastics industry are developing breast cancer and experiencing reproductive problems at elevated rates as a result of these workplace exposures.

Finally, it has been demonstrated that many plastics-related substances are EDCs with adverse effects at very low levels. The ability of EDCs to disrupt the endocrine system at low levels lends biological plausibility to the link between workplace exposures and increased risk of breast cancer and reproductive problems for women working in the plastics industry.

This situation cries out for swift regulatory review and action. If governments can take measures to protect the public from some of the EDCs in consumer products, surely we should expect similar action to protect plastics workers who are more severely and directly exposed. Required actions must include eliminating workers' exposure to hazardous chemicals used in the plastics industry. This can be accomplished most effectively by using substitutes for monomers and additives shown to be endocrine-disrupting chemicals. In addition, a comprehensive regulatory review of chemical hazards is needed. This involves adopting a new paradigm that goes beyond the traditional substance-by-substance review and toxicologic approaches. Attention must also be paid to assessing the health impact of complex mixtures. Furthermore, EDCs must be treated as a class of substances that disturb the normal function of the endocrine system, and therefore must be analyzed through methodologies and principles established in the field of endocrinology [67].

It is our contention that there is sufficient evidence that women working in the plastics industry face serious risks to their health as a result of preventable exposures. It is our hope that this review will generate increased discussion and action on the part of occupational health professionals, industry, and government, and—importantly—among workers and unions.

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Authors' note: Further descriptions of the qualitative study and research methods can be found in book chapters published in academic books: *"Consuming" Chemicals: Law, Science and Policy for Women's Health* [11] and *Rural Women's Health* [68].

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